"On the Luminosity of the Rare Earths when heated *in Vacuo* by means of Cathode Rays." By A. A. CAMPBELL SWINTON. Communicated by LORD KELVIN, F.R.S. Received March 20, —Read April 27, 1899.

For incandescent gas mantles, it is found that certain definite mixtures of the rare earths are necessary, in order to obtain the maximum luminosity. For instance, in the ordinary Bunsen gas flame, a mantle consisting of pure thorium oxide, or of pure cerium oxide, will only give about one-eleventh of the light that is given by a mantle composed of 99 per cent. of thorium oxide, and 1 per cent. of cerium oxide, which is the mixture at present used by the Welsbach Company.

In order to explain this remarkable fact, several different and somewhat contradictory theories have been propounded, one of which implies catalytic or other chemical action between the oxides and the constituents of the Bunsen flame.

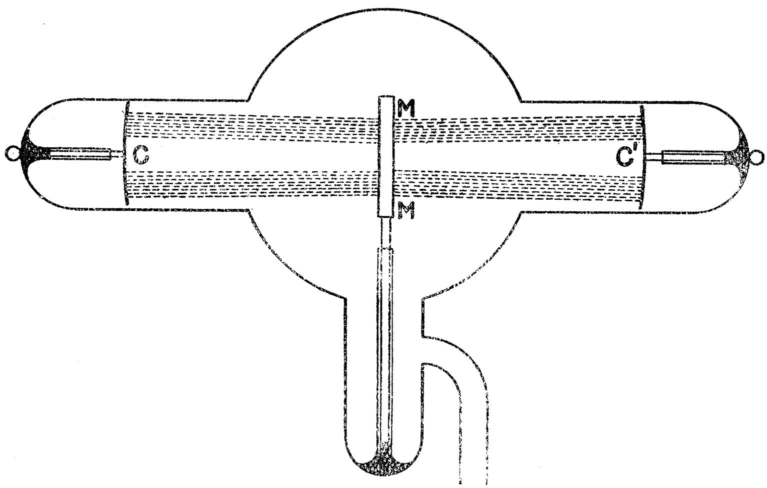
In order to investigate this question, it is obviously important to note the behaviour of the rare earths at high temperatures without contact with any flame, and endeavours have already been made to effect this by heating the oxides in specially constructed furnaces. Under these conditions, only very minute differences could be detected in the amount of light given by different oxides and mixtures, but it appears doubtful whether the very high temperature of the Bunsen flame was really attained.

It has occurred to the writer, that very high incandescence could be produced by enclosing mantles in a vacuum tube, and subjecting them to bombardment by means of cathode rays, when the mantles would not be in contact with anything except the cathode rays themselves, and the comparatively small amount of residual gas that remains in the tube at the requisite high degree of exhaustion.

Since the date of Sir William Crookes's early researches, it has been known that a very high temperature could be produced in a body placed at the focus of the convergent rays from a concave cathode. In this manner Crookes melted platinum and glass, and brought carbon wool to bright incandescence. The writer has made many experiments on this subject, using instead of the interrupted continuous currents employed by previous investigators, alternating electric currents, which appear to have many advantages for this purpose. At the Royal Institution, in February, 1898, the writer showed that very brilliant incandescence could be obtained for a short time in a small block of lime, placed in a suitably exhausted tube midway between two concave electrodes, connected to an alternating electric supply at about 6000 volts pressure, and in June, 1898, at the Royal

Society, he exhibited in action a similar arrangement, but with the block of lime replaced by a flat plate of thorium oxide. In this case the concave electrodes were of such a curvature and were placed so far apart, that the two sides of the thorium plate in each case intersected the diverging cone of cathode rays. Under these conditions nearly a square inch of the thoria surface on each side of the plate became highly incandescent, and a very powerful light was obtained for some minutes at a time, but only at a critical and highly unstable degree of vacuum.

The writer has now applied this method to the investigation of the comparative luminosity of different mixtures of the rare earths.



One form of the tube employed was constructed as shown in the above figure, where C, C′ are two spherically concave discs of aluminium 1·125 inches diameter, and 6 inches radius of curvature. These electrodes are placed about 7 inches apart, and were connected to the secondary terminals of a 10-inch Ruhmkorff coil, the primary of which was supplied through a variable resistance, with alternating electric current at 100 volts pressure from the main. The tube was connected through a drying tube, containing phosphorus pentoxide, to a pair of Toepler pumps, and also to a McLeod gauge.

The mantle M M to be experimented upon, was mounted on a platinum wire frame and placed between the two electrodes, so that as the electric current alternated, and each electrode became in turn cathode, the mantle was subjected on alternate sides to cathode ray bombardment. The curvature of the electrodes was such as to give almost parallel beams of cathode rays, so that a considerable ring

shaped, and slightly hollow, area on each side of the mantle was subjected to the rays, and could be brought to high incandescence.

A preliminary experiment was made with a mantle of asbestos, powdered over in patches with pure thorium oxide. With this it was found that at a suitable degree of exhaustion, the patches of thoria became brilliantly incandescent, with an intensity of cathode rays that made the asbestos barely red hot.

Experiments were next made with mantles consisting entirely of thoria and ceria, both separately, and mixed in different proportions. These mantles were prepared in a similar manner to the Welsbach incandescent gas mantles, by saturating a carefully purified cotton fabric with ammonium nitrate of thorium and cerium, and then burning out the cotton. Very thick and closely woven cotton lamp wick, freed from foreign matter by treatment with caustic soda, hydrochloric acid, and ammonia, was employed in place of the thin fabric usually used, so that the resulting mantle after burning out the cotton, was very close in texture, and fully 0·2 inch thick. This was found necessary, as otherwise some of the cathode rays passed through the mantle and melted the opposite aluminium electrode.

In order to obtain accurate comparisons between pure oxides and different mixtures, the mantles were made in patchwork, each complete mantle being made up of two or four sections, separately impregnated with different solutions, and then sewn together with impregnated cotton before being burnt.

The mantles were so mounted in the vacuum tube that the cathode rays impinged equally upon the portions that consisted of different mixtures, so that an equal amount of energy was imparted to each sample.

With a compound mantle prepared in this way, composed one-half of pure thorium oxide, and the other half of a mixture of 99 per cent. thorium oxide plus 1 per cent. of cerium oxide, it was found after exhaustion that on starting the cathode discharge the thoria plus ceria heated up to incandescence more rapidly, and, on stopping the discharge, cooled more rapidly than the pure thoria. Further, when at full incandescence and observed through a dark glass, the thoria plus ceria was slightly more luminous than the pure thoria, though the difference was very small, probably not more than 5 per cent. Owing to the difficulty of maintaining a constant vacuum, accurate photometrical measurements were not possible, but the amount of light under favourable conditions was roughly estimated at, at least, 150-candle power per square inch of incandescent surface, this being obtained with an expenditure of electrical energy in the secondary circuit at about 8,000 volts pressure of approximately 1 watt per candle. The amount of exhaustion suited to give the best results varied with the dimensions of the tube and the conditions mentioned

below, but was approximately about 0·00005 atmosphere, the maximum luminosity being obtained when the dark spaces of the two cathodes just crossed at the centre of the bulb. Owing to the large amount of gas occluded by the mantle, a proper degree of permanent exhaustion was very difficult to arrive at, and required continuous pumping for many hours with the cathode rays turned on at intervals. Even then the conditions of maximum luminosity were exceedingly unstable, owing to the further liberation of occluded gas on the one hand, and on the other to the rapid increase in the degree of exhaustion owing to absorption of the residual gas by the electrodes. That such absorption probably took place in the aluminium electrodes, and not in the mantle, was demonstrated by other experiments with a tube in which there was no mantle, but only two electrodes of aluminium wire.

After the cathode rays had been allowed to bombard the mantle for a short time, the latter was found to have become discoloured where bombarded. That portion which was composed of pure thoria became dark blue, while the thoria plus ceria became brown. This effect, which appears to be analogous to those observed by Goldstein with lithium chloride and sodium chloride,* seems to be due to a partial reduction of the oxides by the cathode rays. The admission of a very minute quantity of air to the tube while the cathode rays are acting on the mantle, and the latter is in parts incandescent, causes the discoloration to disappear instantaneously on the incandescent, but not upon the cool portions, probably by re-oxidation of the partially reduced oxides, while the discoloration also slowly vanishes in a day or two with the mantle cold if air at ordinary atmospheric pressure is admitted to the tube. By continuing to bombard the mantle with cathode rays, and alternately allowing the vacuum to increase and letting in small quantities of air, the discoloration can be made to appear and to disappear over and over again as often as desired. At the moment of admitting the air, the amount of light was found momentarily to increase, this being probably due to the increased temperature due to the re-oxidation of the partially reduced oxides.

After repeating this process of letting in small quantities of air, and allowing them to be absorbed, several times, it was found that the degree of exhaustion which gave the maximum incandescence had altered from 0·000047 to 0·000112 atmosphere, as measured by the McLeod gauge. Similar effects were obtained with a tube containing no mantle, but only aluminium wire electrodes, the inference being that some change takes place in the residual gas which renders it less conducting.

At a higher degree of exhaustion than that which produced incandescence of the mantle, the pure thoria was found to fluoresce blue,

* 'Wied. Ann.,' 1895, No. 54, p. 371.

and the thoria plus ceria with a yellowish light. The fluorescence in each case was much less bright when the oxides were white than when they had become discoloured by previous bombardment. With very high exhaustions the thoria plus ceria fluoresced the more brightly; at lower exhaustions the pure thoria gave the brighter fluorescence.

On the suggestion of Mr. W. Mackean, the tube was pumped up to a very high vacuum and oxygen admitted. A similar experiment was made with hydrogen, the tube being completely filled with the gas, and then pumped to the proper degree of exhaustion. Though at low exhaustions these gases gave distinctive appearances to the discharge in the tube, no difference in the behaviour of the mantles with them and with air could be detected when once the vacuum reached the degree required for producing incandescence of the mantle.

Further experiments were made with a similar tube containing a compound mantle made up of four sections, composed as follows:—(1) pure ceria, (2) pure thoria, (3) 50 per cent. thoria 50 per cent. ceria, (4) 99 per cent. thoria 1 per cent. ceria.

With an intensity of cathode rays that gave a brilliant light with Nos. 2 and 4, Nos. 1 and 3 were found to give practically no light, becoming barely red hot; while, as before, No. 4 was found to give slightly more light than No. 2, and to heat up more rapidly and cool more rapidly than the latter.

These experiments show that thoria and ceria, both alone and mixed, behave quite differently when heated by cathode ray bombardment than when heated in a Bunsen flame. In the latter, 99 per cent. thoria plus 1 per cent. ceria gives many times as much light as pure thoria alone, while, when incandesced by cathode rays of equal intensity, the difference, though in a similar direction, is exceedingly small. Again, in the flame pure ceria gives just about the same amount of light as pure thoria, while with a given intensity of cathode ray bombardment thoria gives a brilliant light, while ceria gives practically none.

In arriving at any finally satisfactory theory of the luminescent properties of the rare earths, these results with cathode rays, which differ materially from those obtained by other methods of heating, will require to be taken into account.

I am indebted to the courtesy of the Welsbach Incandescent Gas Light Company for the samples of the rare earths with which the above investigations were made; also to the assistance of Mr. J. C. M. Stanton and Mr. H. Tyson Wolff in carrying out the experiments.